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Report No. 95-37

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BETHESDA, MARYLAND

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Report No. 95-37, supported by the Naval Medical Research and Development Command, Bethesda, MD, Department of the Navy, under Work Unit No. 63706N M0095.005-6503. The views expressed in this article are those of the authors and do not reflect the official policy or position of the Department of the Navy, Department of Defense or the U.S. Government. Approved for public release, distribution unlimited.

SUMMARY

Problem

The current shipboard casualty projection system, SHIPCAS, is based on data from eighty naval operations during World War II. Ship structures and weaponry have both changed considerably since the second world war, and the SHIPCAS model should reflect these changes in its casualty sustainment estimates.

Objective

The present investigation seeks to improve SHIPCAS projections by adjusting model parameters to reflect advances in weapon systems and ship structural changes. The adjustments will be derived from data extracted from responses of a subject matter expert (SME) panel.

Approach

Subject matter experts with engineering backgrounds were impaneled to examine the factors associated with potential weapon strikes on contemporary ships and to quantify the likely casualty sustainment relative to attacks on panel-selected reference ships during World War II.

Results

Consensus across panel members was achieved regarding: 1) the present-day weapon threats to U.S. ships, 2) the most comparable weapon-ship combination from the World War II empirical data, and 3) the directional shift in casualty sustainment expected with contemporary weapon-ship combinations. Shipboard casualty projections were then derived for all contemporary weapons systems and U.S. vessels by averaging the projected impacts on casualty sustainment given by the individual panel members.

Conclusion

This methodology should assure that the revised projections more accurately reflect future shipboard casualty incidence. The strategy outlined in the present investigation allows the robustness of the original empirical data to be retained while incorporating into casualty predictions ship structural and weapon systems advances.

CASUALTY SUSTAINMENT DURING NAVAL WARFARE: ADJUSTMENTS TO WORLD WAR II-BASED PROJECTIONS

Accurate forecasts of the casualty incidence likely to be sustained during naval combat operations allow sufficient medical resources to be programmed to treat the expected casualty flows. A shipboard casualty projection system, SHIPCAS[1], has been developed to assist planners in determining likely casualty incidence. SHIPCAS projections are based upon empirical data from eighty naval operations and over 800 ship strikes which occurred during World War II[2,3]. While it is important that casualty projections be firmly grounded in operational reality, it is recognized that ship structures and weaponry have both changed since World War II naval combat and that these changes may impact casualty sustainment.

Though considerable research has been performed investigating the relationship of contemporary weapon strikes to ship damage[4], quantification of the relationship between ship strikes and present-day casualty sustainment is constrained by the lack of naval combat engagements and concomitantly, empirical data. Isolated peacetime and wartime incidents involving U.S. ships have occurred in recent years that yielded casualties; however the small number of these incidents do not lend themselves, with any statistical precision, to providing the foundation for future projections. The current investigation uses large amounts of data from World War II Pacific operations as a baseline for casualty sustainment projections and then adjustments to these estimates are calculated to incorporate the impact of weapons advances and changes to ship structures. The scope of the present investigation is limited to casualty sustainment on ships that are the targets of successful attacks; the subject of ship hit probability is the focus of a concurrent study.

METHOD

Subject Matter Experts (SME) with backgrounds in ship structures, weaponry, and naval operations were recruited to participate on a panel quantifying changes to casualty sustainment

factors. Five former naval officers, representing a wide range of engineering and weapons expertise and averaging 28 years of naval service each, were selected as panel members.

Two weeks before the panel was to be convened, all panel members were provided with 218 pages of documentation on U.S. ships during World War II and Japanese offensive systems. For U.S. forces, this documentation included specifications of ships' armor and structure as well as information on Fleet air defense. For the opposing forces of the Japanese, the pre-panel documentation included specifications of naval planes, bombs, projectiles, guns and ammunition, torpedoes, mines, and fire control equipment. The information on the Japanese forces was extracted from detailed reports compiled by the U.S. Technical Mission to Japan, in 1945 and 1946, and archived at the Navy Historical Center in Washington, D.C.[5] Specifications of U.S. World War II warships were extracted from detailed reference sources[6,7,8]. Additionally, the panel members were provided with basic specifications of present-day missiles, underwater weapons, unguided rockets, guns, and bombs of manufacturers world-wide, as well as more detailed specifications on U.S. present-day ship structures[9,10,11,12,13].

The initial step, once the panel was convened, was to reach consensus on the specific weapons systems which represented potential threats to U.S. ships during contemporary naval combat operations. The SME panel members first reached agreement on the broad categories of offensive weapons (e.g., bombs, torpedoes) representing threats and, then, reached consensus on specific subcategories of weapons (e.g., contact torpedoes, influence torpedoes). Table 1 is a listing of the weapons the panel agreed were possible threats in a naval warfare scenario. A list of surface combatants that panel members found were most likely potential targets is presented in Table 2.

The next phase in the panel proceedings was to quantify the casualties likely to be incurred in present-day shipboard strikes relative to the casualties sustained during attacks on U.S. ships during World War II Pacific operations. For each contemporary "weapon threat by surface combatant" combination, the panel was required to reach consensus on the "weapon x ship" combination from World War II that they believed would be most similar with regard to

casualty sustainment. Table 3 presents the World War II weapons and ships from which the panel members selected the closest parallel in likely casualty sustainment to present-day "weapon x ship" combinations.

The next step was for the SME panel to reach consensus on the directional shift in casualty sustainment when comparing a contemporary "weapon x ship" combination with one from the past. That is, the five members had to agree whether there was likely to be more casualties, less casualties, or no difference in casualty sustainment when contrasting a potential future ship hit with a ship attack from the past. Panel members were directed to base this assessment strictly on their engineering knowledge of past and present ship structures and weapons; no information was provided to them as to the actual numbers of casualties sustained in the prior attacks. These panel activities, including a parallel process to adjust ship hit rates, were accomplished over four full days of meetings. Discussions of which World War II "ship x weapon" combinations were most similar to present-day combinations, and the directional shift in likely casualty sustainment were spirited, however, consensus was reached for each "weapon by ship" combination and the direction of that adjustment. Following this phase each panel member spent one week (40 hours) quantifying what they believed the percentage change in casualty sustainment for each weapon strike would be (e.g., a 25% decrease from the agreed-upon World War II "ship x weapon" combination) and documenting the ship structural/weapon systems factors which contributed to each proposed adjustment.

RESULTS

Tables 4-9 display each contemporary weapon and present-day ship combination in conjunction with the World War II "ship x weapon" combination designated by the SME to be most similar in casualty sustainment. Further, these tables present the mean percentage increase or decrease in anticipated casualty sustainment across the five members of the SME panel, the range of the responses, and the standard deviation among the five responses. Each contemporary weapon type is presented with the factors that the Subject Matter Experts thought had the most impact on casualty sustainment when compared with the World War II "weapon x ship" combinations.

BOMBS

General Purpose Bomb (See Table 4) The general purpose (GP) bomb was thought to be roughly similar to the bombs employed by the Japanese during World War II. For this reason, most of the projected casualty sustainment changes were due to ship structural changes and factors such as damage control improvements rather than to changes in this weapon type. The panel members judged that casualty sustainment caused by a general purpose bomb attack on a CV, CVN, CGN, or FFG would decrease when compared to their respective World War II ship and weapon combinations. Factors contributing to these likely decreases in casualties among the modern ship types were significant improvements in damage control areas such as wireless communications, foam and inert gas flooding systems, smoke clearance systems, and oxygen breathing devices. The conventional and nuclear carriers evidenced the biggest drops in projected casualty sustainment (both around 50%) for the additional reason that modern jet fuel is less flammable than the aviation gasoline used in World War II. An additional contributing factor to the projected decrease in casualty sustainment was the fact that modern ships have less crew density.

The modern day destroyer (DD) was projected to have casualty sustainment similar to that of a World War II light cruiser (CL) in a bomb attack. Because these ships were considered roughly similar in structure and the weapon essentially the same, the casualty sustainment was estimated to be unchanged. The impact on casualty incidence of a smaller crew aboard the contemporary ship was viewed to be offset by the possibility of bomb penetration of the magazines and the additional casualties which might be incurred in such a scenario.

Modern day ships such as the conventional guided missile cruiser (CG) and the Burke class guided missile destroyer (DDG) were rated as having higher casualty sustainment likelihoods than their World War II reference ships. This increase, 20%, is due for the most part to the existence of the vertical launch system (VLS) on these ships and the possibility of a catastrophic explosion resulting from bomb penetration. No such system existed on the CL, the SME-designated counterpart for both of these ships. The Kidd class DDG also was judged to

be susceptible to increased casualties from general purpose bomb penetration, though to a lesser degree since it does not have the VLS. Similarly, about half of DD's have a single VLS (in contrast to the dual system on CGs and Burke class DDGs), thus potentially yielding a lesser increase in casualties.

Shaped-Charge Bomb (See Table 4) Casualty sustainment was projected to increase aboard five ship types (CV, CVN, CG, DD, and DDG) given an attack with a shaped-charge bomb. The largest average projected increase, 42%, was observed for the CG when contrasted with a bomb attack on a light cruiser during the Pacific operations. The increase was largely due to the potential vulnerability of the VLS system and the fact that ordnance is stored near the main deck and crew spaces -- areas that are susceptible to a penetrating bomb that explodes below decks. The next highest projected increase in casualty sustainment was on the Burke class DDG, once again due to the VLS. The susceptibility of the VLS to penetration coupled with the penetrating and improved destructive ability of the shaped-charge bomb combine for a projected 30% increase in casualty sustainment. Increases for the CV and the CVN, both compared to the World War II "carrier x bomb" combination, were due to the chance of magazine and fuel explosions caused by the penetrating bomb. These internal explosions were judged to be magnified since more crew are below decks in the modern ships rather than on the flight deck. The projected increase for the CVN was slightly less than the CV (21% vs. 24%) due to the mitigating effects of more armor on the nuclear carrier. An average of a 20% increase was computed from panel responses for the DD and Kidd class DDG, when compared with World War II bomb attacks on light cruisers. Though a catastrophic loss of ship was mentioned as a possibility if the bomb struck a magazine or engineering space, the superior damage control capabilities aboard these ships would lessen the increase in casualty sustainment compared to other ships undergoing a similar attack, in the view of the panel members.

Only two ships, the CGN and the FFG, did not have projected increases in casualty sustainment when compared to attacks during World War II. The CGN's casualty sustainment was rated as unchanged when contrasted to a World War II heavy cruiser struck by a bomb. The reasons given were its general similarities in design and construction to the CA, except that the

contemporary ship has more armor. This extra armor was deemed to offset the penetration effects of the shaped-charge bomb. The FFG was rated to have a mean decrease in casualty sustainment of 30% when compared to a World War II "destroyer x bomb" combination. The factors contributing to this projected decrease were less crew density, better damage control, and the fact that the shaped-charge bomb is more likely to penetrate completely through this smaller ship rather than lodge below decks and explode. This factor was judged to greatly reduce casualty sustainment since no explosion was expected to occur in inhabited spaces.

<u>Incendiary/White Phosphorus (WP) Bomb (See Table 4)</u> The SME panel concluded that the WP bomb is mainly a danger to topside personnel and personnel that may be injured due to fires started by this weapon. Other possible casualty sustainment might be caused by secondary explosions resulting from the ignition of fuel or ammunition.

Two modern ships, the CV and CVN, were rated by the SME panel to have a likely casualty sustainment similar to that of a World War II bomb attack on a carrier. This reasoning was supported by the fact that both the modern and World War II ships must have personnel above deck to service aircraft and that they would be susceptible to the incendiary effects of the bomb and to any secondary explosions of aircraft, ordnance, or fuel.

All other modern ships (CG, CGN, DD, Burke DDG, Kidd DDG, and FFG) were projected to have a decrease in casualty sustainment with respect to their World War II ship and weapon analogs. Each ship type averaged a projected decrease in casualty sustainment of approximately 60%, primarily due to the SME panel's belief that most of the crew would be on the inside of the ship rather than above deck where the effects of the WP bomb are largely confined. Better present-day fire fighting capability, separate external damage control systems, and less flammable materials were all factors contributing to the likely decreases in casualty sustainment.

<u>Cluster Bomb (Shaped Charge/Penetrating) (See Table 4)</u> The World War II weapon that the SME panel judged to be most similar in effects to the cluster bomb was the suicide

plane. Because the kamikaze attacks generally had a much larger magnitude explosion, a decrease in casualty sustainment was projected for all modern ship and cluster bomb combinations. The modern CV and CVN were projected to have casualty sustainment decreases of lesser magnitudes than other contemporary ships. The main factor contributing to this mitigated decrease is the presence of personnel above decks. These personnel are interspersed among aircraft and are vulnerable to the effects of bomblets and secondary aircraft-related explosions. Overall, however, the projected decrease in casualty sustainment, when compared to bomb attacks on World War II carriers, is supported by such factors as better contemporary damage control, better magazine protection, and less volatility of jet fuel when compared to the aviation gasoline used in the second world war.

The SME panel projections yielded average decreases between 43% and 55% for all other contemporary ships. The panel cited factors such as less personnel topside in contemporary ships, better damage control, and better protection of magazines for the modern CG, CGN, DD, DDGs, and FFG, than the World War II reference ships (light cruisers, heavy cruisers, and destroyers). The major factor noted in all cases is the relatively lighter strike of the cluster bomb's bomblets when compared to a massive suicide plane explosion. The SME panel also noted that larger average decreases in casualty sustainment would have been projected among the CG and Burke class DDG if the vertical launch system were not present. The possibility of cluster ordnance hitting VLS encased missiles was judged to potentially impact casualty sustainment.

PROJECTILES

<u>**Projectiles, Small and Medium Caliber, Airburst (See Table 5)**</u> Small and medium caliber airburst projectiles were all projected to yield decreases in casualty sustainment when compared to gunfire attacks on World War II ships. The panel projected average casualty sustainment decreases of 56% when comparing these types of attacks with gunfire attacks during Pacific operations. Factors contributing to projected decreases in casualty sustainment when comparing modern CVs and CVNs with World War II carriers are the presence today of an

armored steel flight deck, less volatile jet fuel, and greater protected armament. The projected decreases on carriers, however, were not as large as the anticipated casualty sustainment decreases for other ships since the nature of carrier operations requires some topside personnel.

For all contemporary ships, the inability of the small or medium caliber airburst projectile to penetrate into crew spaces was presented as a major factor in the projected casualty decreases. Further, improvements in ship structural strength due to welded vice riveted construction and advances in steel strength were judged to confine this weapon's effects mainly topside, away from most of the crew. These factors yielded average casualty sustainment decreases of approximately 70% for non-carriers attacked by medium and small caliber airburst projectiles.

<u>**Projectiles, Small and Medium Caliber, Contact (See Table 5)**</u> Aircraft-delivered, small caliber projectile attacks on a modern CV or CVN had a projected casualty sustainment increase averaging greater than one hundred percent when compared to gunfire attacks on carriers in World War II. The main factors in this projection were the extremely high rate of fire that can be achieved coupled with the presence of personnel on the flight deck. The added chance of secondary explosions due to aviation fuel and ordnance also contributed to this anticipated casualty sustainment increase.

Aircraft-delivered gunfire attacks on the remaining ships (CG, CGN, DD, both DDGs, and FFG) all yielded projected casualty sustainment levels similar to gunfire attacks on the World War II reference ships. The SME panel's reasoning was that the rapid rate of fire relating to this weapon would be balanced by the fact that there are fewer personnel exposed to the effects of this weapon.

Medium caliber contact projectiles, likely to be delivered by enemy surface vessels, yielded projected decreases in casualty sustainment for all contemporary ships when contrasted with the gunfire attacks of World War II. The SME panel believed that modern day damage control and ship construction would largely be responsible for these decreases. Additionally, the

firepower of the medium caliber round was judged to be generally less than that of its World War II counterpart and this too, would lessen the casualties inflicted.

<u>**Projectiles, Small and Medium Caliber, Internal Blast (See Table 6)**</u> Small caliber internal blast projectiles are not only delivered at a high rate of fire and possess increased penetrating ability, but they also have increased explosive power when compared to World War II gunfire. These factors, as judged by the panel members, caused projected casualty sustainment increases of over 200% for the contemporary CV and CVN when compared to the carriers hit by projectiles during World War II. The possibilities of secondary explosions and fire, along with the likelihood of penetration of the carrier island and hangar areas, were other factors the panel members thought might contribute to an increase in casualty sustainment. Panel members stated that these explosions and penetrations would likely inflict casualties among exposed personnel on the flight deck, as well as in aircraft support areas such as the hangar deck.

The other contemporary ships (CG, CGN, DD, DDG Burke, DDG Kidd, and FFG) have relatively few exposed personnel topside when compared to the aircraft carriers. Compared to the light cruisers, heavy cruisers, and destroyers of World War II, the modern ships also have less crew density. These factors were weighed against the increased explosive power, rates of fire, and penetrating ability of the projectile and resulted in panel members reaching a consensus that similar numbers of casualties would likely be incurred when comparing small caliber, internal blast projectiles of today with the casualty sustainment of gunfire attacks during second world war Pacific operations.

Medium caliber internal blast projectiles, likely to be delivered by enemy surface vessels, were predicted by the panel to yield decreases in projected casualty sustainment for all modern vessels when contrasted with World War II gunfire attacks. The panelists cited factors such as improved modern damage control and enhanced contemporary ship structural design that can withstand, control, and deaden an explosion caused by a medium caliber internal blast projectile hit. Both of these factors contributed substantially to the SME panel's predicted casualty sustainment decreases for all modern vessels.

Projectiles, Small and Medium Caliber, Armor-Piercing (See Table 6) Contemporary, air-delivered, small caliber, armor piercing projectiles not only come at a higher rate of fire than World War II projectiles but also would exhibit increased explosive and penetrating power. These factors led to significant increases in the casualty sustainment estimates on carriers of today when contrasted with casualties incurred in gunfire attacks on carriers during World War II operations. These weapon advances were judged to endanger not only the normal topside personnel needed for flight operations, but also place at risk personnel in the hangar deck and island area of the modern aircraft carrier.

Ships other than carriers were projected to have little change in casualty sustainment if struck by air-delivered armor-piercing projectiles when compared to their World War II analogs. The balancing factors mentioned were that the ship's self defense improvements and better placement of personnel negated the effects of higher rates of fire and the increased penetrating power of these armor-piercing projectiles.

Medium caliber, armor-piercing projectiles, when delivered by surface vessels against modern carriers, yielded casualty projection decreases averaging approximately fifty percent. Modern damage control capabilities and improved blast deadening and absorption were factors mentioned for the decreases on carriers.

Two ship types, the CGN and the FFG were projected to have no change in casualty sustainment levels when comparing a medium caliber, armor-piercing projectile hit with gunfire attacks on the World War II reference ships. The CGN's structural integrity improvements including blast deadening, venting, and absorption were viewed to offset any casualty sustainment increases that normally might be associated with projectile penetration into crew areas. Factors mentioned for the FFG include better placement of personnel and the chance that a larger penetrating projectile might pass entirely through the ship instead of exploding within the vessel.

The remaining contemporary ships (CG, DD, DDG Burke class, and the DDG Kidd class) all were projected to have increases in casualty sustainment if struck by a medium caliber, armor-

piercing projectile. Using a gunfire attack on a light cruiser as their reference point, the contemporary ships were considered "softer" in the sense that they would not withstand a medium caliber penetrating blast as well. Panel members stated that contemporary ships were large enough for the projectile not to pass entirely through, yet small enough that there was the possibility of secondary explosions of ordnance. In addition, the vertical launch system (VLS) was viewed to represent an additional threat of secondary explosion for the CG, DD, and Burke class DDG in the event of projectile penetration. Modern damage control was seen by the panel to mitigate much of the potential casualty sustainment increase, thus yielding expected casualty gains averaging approximately twenty percent for each modern ship type.

<u>Projectiles, White Phosphorus, Medium Caliber, Airburst (See Table 6)</u> All modern ships were judged to have substantial decreases in likely casualty sustainment when comparing a contemporary white phosphorus attack to their World War II counterparts under gunfire attack. The CV and CVN had the smallest estimated decreases in casualty sustainment (46% for both) since they still have exposed personnel on the flight deck that are at risk from a white phosphorus projectile attack. All other contemporary ship types exhibited predicted casualty sustainment decreases of 70% to 75%, due mainly to their lack of exposed topside personnel. This factor, combined with better modern fire fighting capability, improved damage control, and less volatile fuel and ordnance all contributed to the anticipated casualty sustainment decreases.

MISSILES

<u>Missiles, Conventional, Short Range, Solid Fuel, Small Mass (See Table 7)</u> Four ships were rated by the SME panel to have projected casualty sustainment decreases when contrasting a strike by a short range, conventional missile to Japanese bomb attacks. The modern CV and CVN rated the largest casualty sustainment decreases due to the panel belief that the bombs of World War II operations tended to explode on busy flight decks yielding more casualties than would a contemporary short range missile, which would tend to penetrate and explode within the ship. The panel also felt that modern carriers are better designed to withstand internal blasts than their World War II analogs and have improved damage control and fire fighting capabilities.

The contemporary CGN and FFG were judged to have smaller casualty sustainment decreases than the carriers. The CGN's projected decrease was attributed to better armor for nuclear reactor protection and a better blast design than the heavy cruiser with which it was compared. The small size of the FFG was judged to be a factor in that a missile might penetrate through the ship without exploding, contributing to fewer casualties than those sustained in bomb attacks on World War II destroyers. In addition, both ships were credited by the SME panel as having vastly improved fire fighting and damage control capabilities.

The remaining contemporary ships (DD, DDG Burke, DDG Kidd, and CG) were rated to have either increases or no change in casualty sustainment. The contemporary DD was expected to be roughly equal in terms of casualty sustainment when compared to a bomb strike on a light cruiser (CL) during the Pacific operations; while the contemporary DD has better damage control, the CL was judged to have better armor by the panel. Missile hits on the CG and the Burke class DDG, when contrasted with bomb attacks on light cruisers, had predicted casualty sustainment increases averaging about 20%. Both were reported to have less armor than their World War II counterpart, and both are susceptible to VLS penetration and secondary explosions. The Kidd class DDG had a slightly smaller potential casualty sustainment increase, due mostly, in the panel's view, to the absence of the vertical launch system (VLS).

<u>Missiles, Conventional, Long Range, Liquid Fuel, Large Mass (See Table 7)</u> The modern CV and CVN both were projected to have casualty sustainment decreases if struck by a large mass missile when compared to a bomb strike on a World War II aircraft carrier. The panel's reasoning was that bomb attacks caused more topside casualties than would be expected to result internally by a contemporary long range, large mass, conventional missile. The modern aircraft carriers are better designed to withstand internal hits, with such features as bulkhead bracing members, design for hull and bulkhead plating shock criteria, and magazine protection. These factors, along with less volatile contemporary aviation fuel, a steel flight deck, better damage control, and an overall larger design influenced the panel to predict casualty sustainment decreases.

Every other modern ship (the CG, CGN, DD, Burke DDG, Kidd DDG, and FFG) yielded increases in expected casualty sustainment when comparing present-day large mass missile hits with bomb strikes on the World War II reference ships. The panel attributed these potential increases to 1) the fact that these smaller ships have less armor, 2) the greater internal shock of the long range missile which presents a heightened opportunity of hull rupture, and 3) the possibility of explosion from the residual fuel associated with these missiles. Factors thought to mitigate these casualty sustainment increases to a degree were the better damage control and fire fighting capabilities of the contemporary ships.

Missiles, Anti-Radiation (See Table 7) All contemporary ships had predicted casualty sustainment decreases when comparing anti-radiation missile strikes to gunfire attacks during Pacific operations. The panel's reasoning was the same across all ship types -- since contemporary ships have fewer personnel topside, a non-penetrating anti-radiation missile will cause fewer casualties. The predicted casualty sustainment decreases were less for the CV and CVN than for the other contemporary ships since the carriers must still have personnel topside, and these personnel would be susceptible to injury from the high speed fragments of the anti-radiation missile.

Missiles, Shaped-Charge, Short Range, Solid Fuel, Small Mass (See Table 7) All modern ships, with the exception of the CGN and CVN, were projected to have casualty sustainment increases ranging from 30 to 40 percent if struck by a short range, shaped-charge missile when compared to bomb attacks in the Pacific operations. The shaped-charge missile was rated by the panel members to have substantially more destructive power than World War II-era bombs, and the focused charge would be likely to penetrate the hull of all but the most heavily armored modern ships. Panelists believed the penetration would, at times, be combined with secondary effects due to magazine or unused missile propellant explosions. The CGN and CVN were the only contemporary ships that had armor comparable to their World War II counterparts which resulted in slightly smaller projected casualty sustainment increases.

Missiles, Shaped-Charge, Long Range, Liquid Fuel, Large Mass (See Table 7) All modern day ships attacked by large mass, shaped-charge missiles were anticipated by the panel to have casualty sustainment increases when compared to the reference combinations. The major factor mentioned was the size and penetrating power of the shaped-charge, large mass missile. Most panel members felt that the stronger blast and shock, and possible secondary explosions of residual fuel and ordnance would overwhelm all but the largest ships. Adding to the predicted casualty sustainment increases were the panel members' view that the World War II bomb (the reference weapon for this comparison) caused mainly topside casualties since it lacked the penetration power of a missile. Smaller ships such as the contemporary DD, Burke and Kidd class DDG, and FFG were rated to have casualty sustainment increases ranging from 120% to 207%. The dramatic increases in likely casualties aboard these vessels were largely attributable to several panel members challenging the survivability of these ships if attacked by a long range, shaped-charge missile. Larger modern ships (CV, CVN, CG, and CGN) had smaller estimated casualty sustainment increases since they were judged to be better able to absorb such a strike.

TORPEDOES

Torpedoes, Contact, 30-50 kg (See Table 8) Each contemporary ship was predicted to have a casualty sustainment decrease in scenarios involving attacks by a 30-50 kg contact torpedo when compared with torpedo attacks of World War II. The major weapon consideration was the generally smaller warhead of the 30-50 kg weapon when compared with those of Pacific operations. Additionally, the panel mentioned damage control improvements, as well as better structural integrity and improved flooding boundaries as factors in their ratings. Ship size was another factor -- bigger ships had larger expected casualty sustainment decreases (averaging 65% for the carriers) while smaller ships, such as the FFG, averaged an expected decrease of 36% across panel members.

Torpedoes, Influence, 30-50 kg (See Table 8) Panel members chose World War II mines as the reference weapon with which to compare the influence torpedo, and casualty sustainment decreases were projected for all contemporary ship types struck by a 30-50 kg

influence torpedo. Expected casualty decreases were greatest for the larger ships (CV, CVN, CG, and CGN) and slightly less in magnitude for the smaller ships (DD, DDG Burke and Kidd, and FFG). The rationale expressed by the SME panel for this difference was that an influence torpedo detonating under a ship would produce a gas bubble yielding a shock that smaller ships would have much more trouble absorbing. Factors such as better compartmentalization and damage control improvements would contribute greatly to the predicted casualty sustainment decreases across modern ships.

<u>Torpedoes, Contact, 100-300 kg (See Table 8)</u> Contact torpedo attacks on the contemporary carriers were estimated to yield casualty sustainment decreases of 50% when compared with similar attacks during World War II. The major factor mentioned by the panel for this casualty sustainment decrease is the placement of voids (empty spaces that tend to absorb shock) outboard near the hull. This void placement, along with overall better structural design (stronger reinforced materials), blast hardening, improved flooding boundaries, and better damage control all contributed to the predicted casualty sustainment decreases. The contemporary CG likewise was rated to incur fewer casualties than its World War II counterpart, but due to its smaller size the projected decrease was not as pronounced as among carriers.

All other contemporary ships (CGN, DD, Burke DDG, Kidd DDG, and FFG) had estimated casualty sustainment levels which paralleled the reference ships of World War II. Advances in torpedo technology were viewed by the SME panel as a factor which generally tended to increase casualty sustainment estimates, while structural and damage control improvements among the contemporary vessels were factors which tended to decrease likely casualties. These two factors were judged to negate one another and yielded estimates of "no change" in casualty sustainment.

<u>Torpedoes, Influence, 100-300 kg (See Table 8)</u> Contemporary carriers were judged by the SME panelists to sustain roughly similar levels of casualties when attacked by torpedoes with large warheads as carriers struck by torpedoes during World War II operations. The increased destructive power of the contemporary influence explosive, the better reliability

of the exploder, and the increased possibility of the explosive detonating under the ship, were all factors the panelists felt would increase casualties. However, better damage control and improved structural integrity factors, when combined with the blast deadening and absorption properties of today's larger carriers were judged by the panelists to offset the advances in weapon technology yielding no net gain or loss in expected casualties.

The smaller ships (CG, DD, both classes of DDG, CGN, and FFG) all were rated to incur casualty sustainment increases when compared with their World War II counterparts. Panel members held out the possibility that a cruiser attacked by an influence torpedo would suffer a broken keel and loss of longitudinal integrity due to an undership detonation. Casualty sustainment increases of approximately 90% were projected for the CG and CGN when contrasted with World War II torpedo strikes on a light cruiser and heavy cruiser respectively. The contemporary destroyers (DD, DDG Burke, DDG Kidd) were cited by the panel as not likely to survive an undership explosion due to likely structural beam folding and separation. The panel also felt the smaller FFG's survival would be in question since it would most likely suffer massive hull deformation and seam splitting. If a smaller ship were to survive, increased casualty sustainment would likely still result from the significant shock effect felt from the under hull gas bubble and possible flooding. For these reasons, expected casualty sustainment increases on the destroyers and frigates were rated very high -- in a range of 114% to 120% when contrasted with the World War II analogs.

MINES

Mines, Contact (See Table 9) Casualty sustainment associated with contact mines was judged by the panelists to decrease for all modern ships when compared to their second world war counterparts primarily due to the same weapon technology being used on ships that have since undergone significant structural improvements. Factors such as better damage control, improved structural integrity, flooding boundaries, and shock hardening served to decrease casualty sustainment estimates for the modern vessels.

Smaller ships (destroyers and frigates) were projected to have lesser magnitude casualty sustainment decreases than the larger ships. Personnel on smaller ships would presumably be closer to the blast area and secondary injuries due to the shock effect would be more likely. The risk of hull rupture on smaller ships was also judged to be greater and likewise contributed to a dampening of expected casualty reductions when compared to carriers and cruisers.

Mines, Influence (See Table 9) Similarly, ship designs more capable of sustaining an influence mine hit, along with structural hardening, better flooding boundaries, improved equipment shock mounting and damage control were all factors mentioned by the panel as reasons why contemporary ships were expected to incur fewer casualties than their World War II analogs. Carriers were projected to observe the biggest decreases in casualties (~ 50%), while smaller ships had estimated decreases ranging from 20% to 30%.

DISCUSSION

Subject matter experts (SME) with engineering backgrounds were impaneled to examine the factors associated with potential weapon strikes on contemporary ships and to quantify the likely casualty sustainment relative to attacks during World War II. This methodology will be used to factor recent changes to weapons and ships into casualty projections while preserving the robustness of the original empirical data.

All modern ships were reported by the SME panel to have undergone vast improvements in damage control and structural design. In addition, modern ships were reported to require less personnel due to advanced automated systems. Damage control improvements over World War II-type vessels include wireless communications, advanced smoke clearance systems, alternate damage control central locations, more and better equipped damage control lockers, oxygen breathing devices, and advanced fire fighting and fire prevention techniques. These damage control improvements were mentioned in conjunction with every modern ship and serve to decrease casualty sustainment by preventing and controlling the spread of fires, containing

flooding incidents, and providing such life-saving devices as the oxygen breathing apparatus in case of smoke or lack of oxygen.

Modern ship structural improvements such as welded construction (instead of riveted construction), stronger homogenous steel, more compartmentalization, bulkhead bracing members, shock mounting of equipment, and better magazine protection were also thought to contribute to fewer casualties in the event of a weapon strike. The structural improvements combined with less modern crew density further influenced the panel in the direction of casualty sustainment decreases overall.

Other trends involved factors that were ship-type specific. Nuclear powered carriers and cruisers were rated to have larger casualty sustainment decreases and smaller casualty sustainment increases than other ships because panel members judged that the extra armor used to shield the nuclear reactors on these ships would also serve to lessen casualty sustainment. Bomb and missile attacks on Burke class guided missile destroyers (DDG), conventional guided missile cruisers (CG), and in some instances destroyers (DD) were rated to have increased casualty sustainment levels when compared to the Kidd class guided missile destroyer (DDG) and nuclear guided missile cruiser due to the possibility of a penetrating-type weapon passing through the vertical launch system (VLS) and causing internal secondary explosions that might place the ship's survivability in doubt. Lastly, the panel generally estimated likely casualty sustainment on smaller ships to be greater than on larger ships as the smaller ships have less size and material to absorb shock, and there is a heightened chance of a catastrophic loss of the smaller vessels.

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Table 1. Contemporary Weapon Threats

Bombs:
General Purpose Bomb Shaped-Charge Bomb Incendiary White Phosphorus Bomb Cluster Bomb
Projectiles:
Small Caliber; High Explosive; Airburst Medium Caliber; High Explosive; Airburst Small Caliber; High Explosive; Contact Medium Caliber; High Explosive; Contact Small Caliber; High Explosive; Internal Blast Medium Caliber; High Explosive; Internal Blast Armor Piercing; Small Caliber Armor Piercing; Medium Caliber White Phosphorus; Medium Caliber; Airburst
Missiles:
Conventional; Short Range, Solid Fuel, Small Mass Conventional; Long Range, Liquid Fuel, Large Mass Anti-Radiation Shaped-Charge; Short Range, Solid Fuel, Small Mass Shaped-Charge; Long Range, Liquid Fuel, Large Mass
Torpedoes:
Contact; 30-50 Kg Influence; 30-50 Kg Contact; 100-300 Kg Influence; 100-300 Kg
Mines:
Contact Influence

Table 2. Surface Combatants, Modem

CV	Conventional Aircraft Carrier
CVN	Nuclear Powered Aircraft Carrier
CG	Guided Missile Cruiser
CGN	Nuclear Powered Guided Missile Cruiser
DD	Destroyer
DDG (Burke)	Burke Class Guided Missile Destroyer
DDG (Kidd)	Kidd Class Guided Missile Destroyer
FFG	Guided Missile Fast Frigate

Table 3. Weapon Types and Ship Types Used by SME Panel to Contrast Expected Casualty Sustainment During Contemporary Attacks

WWII Ships	
CV	Aircraft Carrier
CL	Light Cruiser
CA	Heavy Cruiser
DD	Destroyer
DE	Destroyer Escort
WWII Weapons	
Bomb	
Kamikaze	
Gunfire	
Torpedo	
Mine	

Table 4. Projected Casualty Sustainment Changes for Bomb Types

	General Purpose Bomb	Shaped-Charge Bomb	White Phosphorus Bomb	Cluster Bomb
Conventional Aircraft Carrier (CV)	CV x Bomb Decrease 48% 5-95 38.5	CV x Bomb Increase 24% 15-30 6.5	CV x Bomb Unchanged --- ---	CV x Kamikaze Decrease 37% 5-60 21.1
Nuclear Powered Aircraft Carrier (CVN)	CV x Bomb Decrease 52% 10-95 39.2	CV x Bomb Increase 21% 10-30 7.4	CV x Bomb Unchanged --- ---	CV x Kamikaze Decrease 42% 10-75 23.6
Guided Missile Cruiser (CG)	CL x Bomb Increase 22% 5-50 18.2	CL x Bomb Increase 42% 20-65 16.8	CL x Bomb Decrease 62% 5-100 36.5	CL x Kamikaze Decrease 44% 5-80 33.0
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Bomb Decrease 34% 10-50 14.8	CA x Bomb Unchanged --- ---	CA x Bomb Decrease 60% 5-100 35.9	CA x Kamikaze Decrease 52% 5-80 33.3
Destroyer (DD)	CL x Bomb Unchanged --- ---	CL x Bomb Increase 20% 15-35 8.7	CL x Bomb Decrease 62% 5-100 36.5	CL x Kamikaze Decrease 52% 5-80 32.9
Burke Class Guided Missile Destroyer (DDG)	CL x Bomb Increase 22% 10-50 17.9	CL x Bomb Increase 30% 20-50 14.6	CL x Bomb Decrease 66% 5-100 36.3	CL x Kamikaze Decrease 49% 5-90 39.4
Kidd Class Guided Missile Destroyer (DDG)	CL x Bomb Increase 13% 5-25 7.6	CL x Bomb Increase 20% 15-35 8.7	CL x Bomb Decrease 60% 5-100 38.9	CL x Kamikaze Decrease 55% 5-90 36.1
Guided Missile Fast Frigate (FFG)	DD x Bomb Decrease 19% 5-35 11.9	DD x Bomb Decrease 30% 5-55 24.0	DD x Bomb Decrease 57% 5-100 36.0	DD x Kamikaze Decrease 43% 5-70 28.6

LEGEND:

WWII SHIP X WEAPON REFERENCE COMBINATION MEAN INCREASE OR DECREASE (%) RANGE STD. DEVIATION

Table 5. Projected Casualty Sustainment Changes for Projectile Types

	Small Caliber Airburst Projectile	Medium Caliber Airburst Projectile	Small Caliber Contact Projectile	Medium Caliber Contact Projectile
Conventional Aircraft Carrier (CV)	CV x Gunfire Decrease 57% 10-100 39.6	CV x Gunfire Decrease 56% 5-98 40.6	CV x Gunfire Increase 128% 5-500 211.4	CV x Gunfire Decrease 46% 5-95 40.5
Nuclear Powered Aircraft Carrier (CVN)	CV x Gunfire Decrease 57% 10-100 39.6	CV x Gunfire Decrease 56% 8-98 39.7	CV x Gunfire Increase 118% 5-450 189.5	CV x Gunfire Decrease 47% 5-95 41.6
Guided Missile Cruiser (CG)	CL x Gunfire Decrease 72% 10-100 38.2	CL x Gunfire Decrease 68% 5-98 38.1	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 46% 5-90 40.0
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Gunfire Decrease 73% 10-100 37.8	CA x Gunfire Decrease 69% 5-98 37.9	CA x Gunfire Unchanged --- ---	CA x Gunfire Decrease 51% 5-90 34.9
Destroyer (DD)	CL x Gunfire Decrease 72% 10-100 38.2	CL x Gunfire Decrease 68% 5-98 38.1	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 45% 5-90 33.5
Burke Class Guided Missile Destroyer (DDG)	CL x Gunfire Decrease 75% 10-100 37.6	CL x Gunfire Decrease 71% 5-98 37.9	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 45% 5-90 36.4
Kidd Class Guided Missile Destroyer (DDG)	CL x Gunfire Decrease 72% 10-100 38.2	CL x Gunfire Decrease 67% 5-98 37.2	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 45% 5-90 33.5
Guided Missile Fast Frigate (FFG)	DD x Gunfire Decrease 70% 10-100 37.2	DD x Gunfire Decrease 65% 5-98 36.6	DD x Gunfire Unchanged --- ---	DD x Gunfire Decrease 35% 5-90 33.3

LEGEND:

WWII SHIP X WEAPON
REFERENCE COMBINATION

MEAN INCREASE
OR DECREASE (%)

RANGE STD. DEVIATION

Table 6. Projected Casualty Sustainment Changes for Projectile Types

	Small Caliber Internal Blast Projectile	Medium Caliber Internal Blast Projectile	Small Caliber Armor Piercing Projectile	Medium Caliber Armor Piercing Projectile	White Phosphorus Projectile
Conventional Aircraft Carrier (CV)	CV x Gunfire Increase 231% 5-1000 431.5	CV x Gunfire Decrease 53% 5-80 30.9	CV x Gunfire Increase 234% 5-1000 429.7	CV x Gunfire Decrease 45% 5-80 26.9	CV x Gunfire Decrease 46% 5-90 34.2
Nuclear Powered Aircraft Carrier (CVN)	CV x Gunfire Increase 231% 5-1000 431.5	CV x Gunfire Decrease 57% 5-85 34.0	CV x Gunfire Increase 234% 5-1000 429.7	CV x Gunfire Decrease 51% 5-80 29.7	CV x Gunfire Decrease 46% 5-90 34.2
Guided Missile Cruiser (CG)	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 35% 5-70 23.2	CL x Gunfire Unchanged --- ---	CL x Gunfire Increase 19% 10-30 7.4	CL x Gunfire Decrease 74% 5-100 40.3
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Gunfire Unchanged --- ---	CA x Gunfire Decrease 38% 5-70 23.6	CA x Gunfire Unchanged --- ---	CA x Gunfire Unchanged --- ---	CA x Gunfire Decrease 75% 5-100 40.3
Destroyer (DD)	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 34% 5-70 23.3	CL x Gunfire Unchanged --- ---	CL x Gunfire Increase 16% 10-25 8.2	CL x Gunfire Decrease 75% 5-100 40.3
Burke Class Guided Missile Destroyer (DDG)	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 39% 5-70 26.1	CL x Gunfire Unchanged --- ---	CL x Gunfire Increase 13% 10-25 6.7	CL x Gunfire Decrease 75% 5-100 40.3
Kidd Class Guided Missile Destroyer (DDG)	CL x Gunfire Unchanged --- ---	CL x Gunfire Decrease 35% 5-70 23.2	CL x Gunfire Unchanged --- ---	CL x Gunfire Increase 19% 10-30 10.2	CL x Gunfire Decrease 75% 5-100 40.3
Guided Missile Fast Frigate (FFG)	DD x Gunfire Unchanged --- ---	DD x Gunfire Decrease 30% 5-70 27.2	DD x Gunfire Unchanged --- ---	DD x Gunfire Unchanged --- ---	DD x Gunfire Decrease 70% 5-95 37.1

LEGEND:

WWII SHIP X WEAPON REFERENCE COMBINATION
MEAN INCREASE OR DECREASE(%)
RANGE STD. DEVIATION

Table 7. Projected Casualty Sustainment Changes for Missile Types

	Conventional Short Range Small Mass Missile	Conventional Long Range Large Mass Missile	Anti-Radiation Missile	Shaped-Charge Short Range Small Mass Missile	Shaped-Charge Long Range Large Mass Missile
Conventional Aircraft Carrier (CV)	CV x Bomb Decrease 53% 5-90 38.5	CV x Bomb Decrease 50% 5-85 39.2	CV x Gunfire Decrease 31% 10-95 36.8	CV x Bomb Increase 47% 5-150 60.1	CV x Bomb Increase 101% 20-300 118.5
Nuclear Powered Aircraft Carrier (CVN)	CV x Bomb Decrease 57% 10-90 38.7	CV x Bomb Decrease 54% 10-90 40.4	CV x Gunfire Decrease 31% 10-95 36.8	CV x Bomb Increase 21% 1-50 20.5	CV x Bomb Increase 68% 15-150 62.9
Guided Missile Cruiser (CG)	CL x Bomb Increase 21% 7-40 11.8	CL x Bomb Increase 37% 15-60 18.2	CL x Gunfire Decrease 74% 5-99 39.1	CL x Bomb Increase 43% 20-100 34.2	CL x Bomb Increase 136% 30-300 128.4
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Bomb Decrease 30% 5-60 23.2	CA x Bomb Increase 18% 10-20 4.5	CA x Gunfire Decrease 76% 5-99 39.8	CA x Bomb Increase 29% 2-35 30.8	CA x Bomb Increase 104% 25-250 102.7
Destroyer (DD)	CL x Bomb Unchanged --- ---	CL x Bomb Increase 40 % 15-100 34.5	CL x Gunfire Decrease 74% 5-99 39.1	CL x Bomb Increase 42% 20-80 24.1	CL x Bomb Increase 124% 30-300 113.3
Burke Class Guided Missile Destroyer (DDG)	CL x Bomb Increase 21% 10-40 12.2	CL x Bomb Increase 46% 8-100 35.8	CL x Gunfire Decrease 77% 5-99 40.3	CL x Bomb Increase 44% 20-100 33.4	CL x Bomb Increase 139% 30-300 125.9
Kidd Class Guided Missile Destroyer (DDG)	CL x Bomb Increase 11% 5-20 5.4	CL x Bomb Increase 56% 8-200 81.1	CL x Gunfire Decrease 74% 5-99 39.1	CL x Bomb Increase 36% 25-80 24.6	CL x Bomb Increase 152% 30-300 110.7
Guided Missile Fast Frigate (FFG)	DD x Bomb Decrease 17% 5-33 11.8	DD x Bomb Increase 38% 5-150 62.9	DD x Gunfire Decrease 68% 5-99 38.3	DD x Bomb Increase 32% 5-90 33.5	DD x Bomb Increase 207% 30-400 159.8

LEGEND:

WWII SHIP X WEAPON REFERENCE COMBINATION
MEAN INCREASE OR DECREASE(%)
RANGE STD. DEVIATION

Table 8. Projected Casualty Sustainment Changes for Torpedo Types

	30-50KG Contact Torpedo	30-50KG Influence Torpedo	100-300KG Contact Torpedo	100-300KG Influence Torpedo
Conventional Aircraft Carrier (CV)	CV x Torpedo Decrease 64% 15-95 31.9	CV x Mine Decrease 62% 10-95 35.5	CV x Torpedo Decrease 49% 10-90 36.8	CV x Torpedo Unchanged --- ---
Nuclear Powered Aircraft Carrier (CVN)	CV x Torpedo Decrease 67% 15-99 34.3	CV x Mine Decrease 66% 15-99 34.7	CV x Torpedo Decrease 54% 15-95 37.6	CV x Torpedo Unchanged --- ---
Guided Missile Cruiser (CG)	CL x Torpedo Decrease 54% 10-95 32.7	CL x Mine Decrease 50% 10-95 32.2	CL x Torpedo Decrease 17% 0-40 15.6	CL x Torpedo Increase 97% 5-400 169.7
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Torpedo Decrease 59% 10-99 34.8	CA x Mine Decrease 55% 10-99 35.4	CA x Torpedo Unchanged --- ---	CA x Torpedo Increase 91% 2-400 172.7
Destroyer (DD)	CL x Torpedo Decrease 51% 10-90 32.5	CL x Mine Decrease 32% 10-60 23.6	CL x Torpedo Unchanged --- ---	CL x Torpedo Increase 119% 5-500 213.3
Burke Class Guided Missile Destroyer (DDG)	CL x Torpedo Decrease 55% 10-90 31.2	CL x Mine Decrease 39% 10-70 23.6	CL x Torpedo Unchanged --- ---	CL x Torpedo Increase 120% 5-500 213.0
Kidd Class Guided Missile Destroyer (DDG)	CL x Torpedo Decrease 52% 10-90 30.3	CL x Mine Decrease 33% 10-60 21.7	CL x Torpedo Unchanged --- ---	CL x Torpedo Increase 114% 5-500 215.9
Guided Missile Fast Frigate (FFG)	DD x Torpedo Decrease 36% 5-70 25.3	DD x Mine Decrease 24% 5-50 23.8	DD x Torpedo Unchanged --- ---	DD x Torpedo Increase 118% 5-500 214.0

LEGEND:

WWII SHIP X WEAPON
REFERENCE COMBINATION

MEAN INCREASE
OR DECREASE (%)

RANGE STD. DEVIATION

Table 9. Projected Casualty Sustainment Changes for Mine Types

	Contact Mine	Influence Mine
Conventional Aircraft Carrier (CV)	CV x Mine Decrease 56% 5-90 36.6	CV x Mine Decrease 44% 5-85 31.9
Nuclear Powered Aircraft Carrier (CVN)	CV x Mine Decrease 62% 10-95 39.1	CV x Mine Decrease 51% 10-95 35.4
Guided Missile Cruiser (CG)	CL x Mine Decrease 44% 5-90 39.3	CL x Mine Decrease 24% 5-60 23.6
Nuclear Powered Guided Missile Cruiser (CGN)	CA x Mine Decrease 50% 5-95 38.7	CA x Mine Decrease 30% 5-65 23.4
Destroyer (DD)	CL x Mine Decrease 42% 5-85 34.6	CL x Mine Decrease 22% 3-50 20.3
Burke Class Guided Missile Destroyer (DDG)	CL x Mine Decrease 43% 5-85 35.5	CL x Mine Decrease 24% 3-50 22.4
Kidd Class Guided Missile Destroyer (DDG)	CL x Mine Decrease 44% 5-85 32.9	CL x Mine Decrease 22% 3-50 20.3
Guided Missile Fast Frigate (FFG)	DD x Mine Decrease 35% 5-70 28.3	DD x Mine Decrease 19% 3-40 15.2

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WWII SHIP X WEAPON REFERENCE COMBINATION
MEAN INCREASE OR DECREASE (%)
RANGE STD. DEVIATION

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
12/20/95

3. REPORT TYPE AND DATE COVERED
Final 11/94-12/95

4. TITLE AND SUBTITLE
Casualty Sustainment During Naval Warfare: Adjustments to World War II-Based Projections

5. FUNDING NUMBERS
Program Element: 63706N
Work Unit Number:
M0095.005-6503

6. AUTHOR(S) Jeffrey S. Marks, Christoper G. Blood, Patricia A. Gilman

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Health Research Center
P. O. Box 85122
San Diego, CA 92186-5122

8. PERFORMING ORGANIZATION
Report No. 95-37

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Medical Research and Development Command
National Naval Medical Center
Building 1, Tower 2
Bethesda, MD 20889-5044

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Projections for the shipboard casualty projection model, SHIPCAS, were updated by adjusting parameters to reflect advances in weapon systems and ship structural changes. The adjustments were derived from the responses of a subject matter expert (SME) panel which examined the factors associated with potential weapon strikes on contemporary ships and quantified the likely casualty sustainment relative to attacks occurring in the past. Modern ship structural improvements were thought to contribute to fewer casualties in the event of a weapon strike. The structural improvements combined with less modern crew density further influenced the panel in the direction of casualty sustainment decreases overall. The panel generally estimated likely casualty sustainment on smaller ships to be greater than that on larger ships as the smaller ships have less size and material to absorb shock, and there is a heightened chance of a catastrophic loss of the smaller vessels.

14. SUBJECT TERMS
Casualty Sustainment, Subject Matter Expert Panel, Shipboard Casualty Projections, Weapon and Ship Combinations

15. NUMBER OF PAGES
30

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited